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THz-TDS of Filter Paper at Differing Humidities

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Abstract—Characterisation of filter paper using Terahertz Time Domain Spectroscopy (THz-TDS) is given at different humidities. This is achieved using saturated salt solutions. The absorption coefficient of filter paper increases with frequency and relative humidity.

I. INTRODUCTION AND BACKGROUND

TERAHERTZ (THz) Time Domain Spectroscopy (TDS) has been used to determine a number of materials properties, ranging from simple materials such as glass¹ to more complex samples such as biological proteins, liquid crystals, cancer, and more. THz security screening relies upon specific ‘fingerprints’, or absorptions in the THz region which can identify a material’s unique structure.

There have been many articles published detailing characterisation of these ‘fingerprints’ and material properties in the THz region. These have provided valuable information and new insight into protein conformational dynamics and THz detection in security applications. There is a general consensus that the hydration of proteins strongly affects their function². The ultimate aim is to study proteins using THz-TDS at differing hydration levels. Structural changes that occur in proteins during hydration/dehydration can also affect the water absorption behavior of proteins²; this is prominent in the THz region due to its strong absorption in water.

Firstly, filter paper will be used as a sample to check the method of THz-TDS at differing humidities using saturated salt solutions. There are currently papers on filter paper using other methods such as nuclear scattering experiments yielding interesting results³.

The optimum thickness of the sample in THz-TDS needs to be considered and is given by $t_{optimum} = \frac{\alpha(\omega)}{2}$, where α is the absorption coefficient⁴. Thus we are using 7 filter paper pieces to give an optimum thickness of 0.99 ± 0.04 mm. This method will also be employed on proteins such as Lysozyme in future.

II. MATERIALS AND METHODS

THz-TDS results are taken at approximate Relative Humidities (RH) of 94%, 81%, 71%, 64%, and 12% using Potassium Sulfate, Potassium Chloride, Sodium Chloride, Ammonium Nitrate, and Lithium Chloride saturated solutions respectively. Scans are also recorded equilibrating to the particular RH%. The references are averaged on either side of these sample scans to obtain readings at the correct RH. Spectroscopy results are taken using a 12 femtosecond laser incident upon an indium arsenide emitter which generates THz. This is split into the pump and probe beam then

recombines to give measurements between 0.15-1.08 THz. Specifics on this set-up and analysis technique can be found in [5]. The RH levels are read with a Wavetek meter with accuracy of 3% RH. Saturated scans are taken over 1h.

Measurements were also taken with a FIRL-100 Laser for corroboration. The FIRL-100 laser system uses a CO₂ laser with the pump source for the FIRL-100 laser. References were taken by placing an Aluminum sheet between the laser and the detector. Due to the lack of stability of the output signal, reference measurements were taken both before and after each filter paper measurement, and then averaged.

III. RESULTS

Results from the 12 femtosecond THz-TDS system using 7 pieces of filter paper are displayed in Fig. 2.

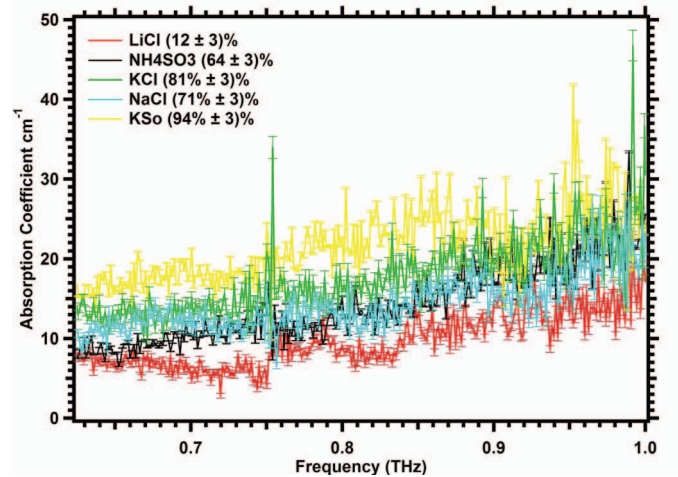


Fig. 1. Filter paper absorption coefficient’s as a function of frequency at various saturated RH%. Scans are taken over 1h for good resolution.

The filter paper is at room temperature, $(21 \pm 3)^\circ\text{C}$, at saturation RH%. Fig. 1 shows an increase of absorption coefficient with RH as expected. Scans taken leading up to the saturation humidity levels also showed this. There are a fixed number of sites for bound water. As the sorbed water increases with RH these are filled and the rest are partitioned as free water. The range of Fig. 1 has been limited to 0.625-1.00 THz as anomalies occurred in the range before this. The absorption coefficients are shown to increase with increasing frequency.

One piece of filter paper was then used as a sample to check the optimum thickness and verify results. This is shown in Fig. 2. Results were taken over 10 minutes, five times, for both the sample and reference then averaged. Due to the lower signal to noise ratio (SNR), some absorption lines do not increase with an increase in RH%, namely KCl (81% RH). However this result may still be higher and is still within experimental

errors. This also verifies that the optimum thickness is better for 7 pieces as determined by the relationship from [4].

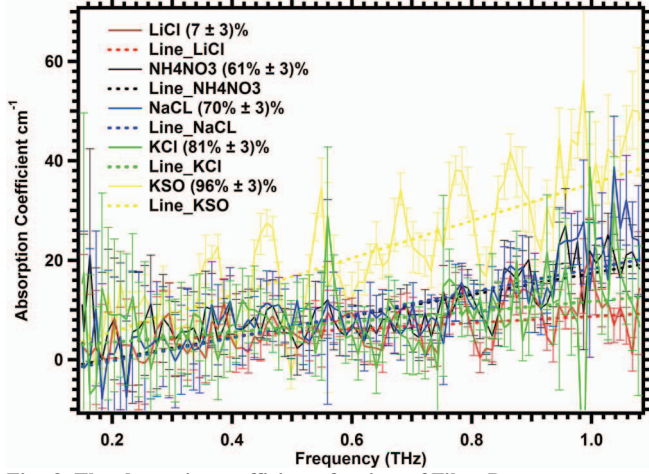


Fig. 2. The absorption coefficient of a piece of Filter Paper.

The absorption coefficient of one piece of filter paper increases with frequency over 0.15-1.08 THz. This agrees with the data from 7 pieces.

Results from the FIRL-100 Laser gave an absorption coefficient at 2.52 THz of $(94.6 \pm 0.9) \text{ cm}^{-1}$, as seen in Fig. 3.

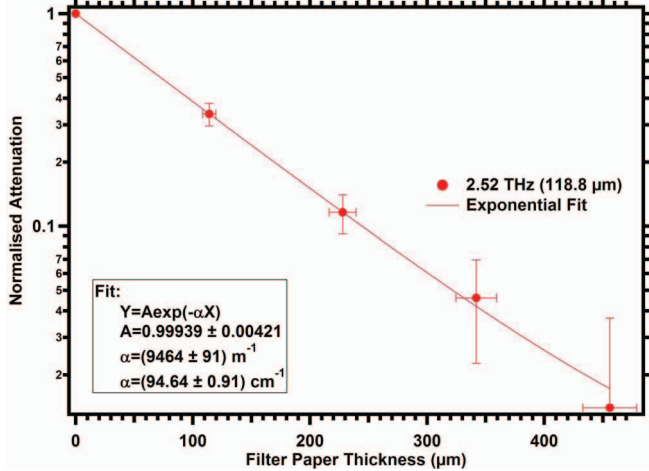


Fig. 3. Absorption coefficient at 2.52THz (38% RH).

This was calculated again at 45% for 2.52 and 3.11 THz. The absorption coefficients at 2.52 THz and 3.11 THz agree at 45% with an extended absorption fit (see Fig. 4) from the TDS system of $\alpha = 17f^2 + f$ where f is the frequency in THz and α is the absorption coefficient in cm^{-1} .

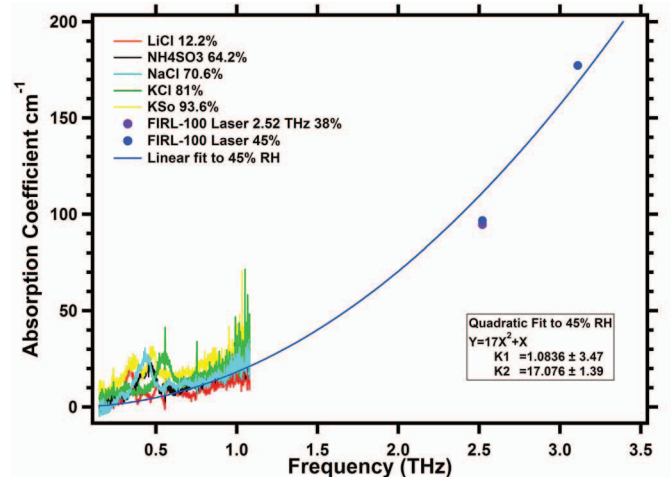


Fig. 4. Corroboration of TDS data with FIRL-100.

IV. CONCLUSION

The absorption coefficient of filter paper increases with both frequency and relative humidity. The absorption increases with frequency in the range 0.65-2.52 THz.

ACKNOWLEDGEMENTS

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